AN INDOOR AIR QUALITY SURVEY OF TWENTY-SIX SWISS OFFICE BUILDINGS

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In an effort to characterize the major factors influencing air quality in buildings in Switzerland, 26 representative buildings were selected for this study. Each building was subjected to the same indoor air quality survey methodology. The most significant cause of air quality problems was found to be poor ventilation, followed by inadequate filtration and poor hygiene. Control of Legionella bacteria and asbestos-containing materials may also require high priority in order to prevent immediate and long term hazards to building occupants.

INTRODUCTION

There is a continuing requirement for air quality data on buildings not classified as "sick" which are representative of buildings as a whole within a specific region or country. Currently, data on levels of many common indoor pollutants in Switzerland are sparse. In addition, it has been shown in the U.S. (1,2,3) that maintenance activities and the condition of air handling equipment can have a profound affect on indoor air quality. Information on these factors in Switzerland is equally hard to find.

This survey selected and evaluated a representative group of 26 commercial office buildings comprising a total of approximately 102,300 square meters of office space in 20 cities in Switzerland. The objective of this survey was to provide contributory data for future mitigation policies, as well as to help set guidelines for suitable ventilation rates and filtration standards in particular. These studies were carried out from the 7th of February to the 15th of March 1989. The buildings selected for this survey were of a wide variety in terms of their size, construction and use. However, a standard methodology to investigate each building was applied.

METHODOLOGY

Although a standard approach was used to survey each building, it required flexibility to cope with different types of buildings examined.

Initial Walk Through

Since one of the objectives of this survey was to assess maintenance standards, each study commenced with an interview with the personnel responsible for maintenance of the building. Questions were designed to elicit operative details such as system on/off times; fresh air, return air and exhaust settings; scheduled maintenance routines; and complaint areas, if any, but did not include questioning of the occupants. There was a walk through of each building to

identify obvious building configurations or design features which could influence air quality in the occupied areas. This was followed by a complete visual inspection of the internals of the building's ventilation system, if any. A visual inspection was also made of the internals of the main air supply ductwork leaving each air handling unit. Where necessary, access was gained to this ductwork by the installation of a small access port and the insertion of a fiber optic borescope.

Qualitative Sampling

In each air handling unit and main air supply duct, a series of samples were also collected on cellulose ester filters for light microscopy analysis. Surface microbe samples were collected on Random Organism Detection and Counting (RODAC) agar plates, to be subsequently incubated, counted, and identified.

A laser particle counter with a size-selective inlet for sampling particles with an aerodynamic diameter of 0.5 microns and above, was used to count particles inside the ductwork. At least two points were sampled inside each major run of ductwork. This qualitative information on the building, along with the location of the samples and the building engineer questionnaire, was prepared on a set of standard field notes to ensure consistency. In the case of buildings not equipped with forced air ventilation systems, this walk through and sampling phase was obviously more limited in scope.

Quantitative Air Sampling

A set of locations were identified in each building to be used for quantitative airborne sampling. These locations were spread evenly throughout the study area of each building with a minimum of two locations per floor, as well as an outdoor control sample point. The following parameters were measured at each location where relevant and appropriate:

- Respirable airborne particle counts, using a piezoelectric microbalance;
- Carbon dioxide levels, using a non-dispersive infrared absorption portable gas analyzer;
- Carbon monoxide concentrations, using a controlled potential electrolysis detector;
- Airborne nicotine (after Ogden et al (4)), with a personal universal flow sampling pump;
- Temperature, using a miniature platinum Pt 100 resistance sensor; and
- Relative humidity, using a chromed layered capacitative electrode.

The following parameters were measured in at least two selected locations in each building:

- Miscellaneous gases, using Gastec calibrated detector tubes.
- Airborne microbial counts, using a centrifugal air sampler employing impaction onto an agar lined drum;
- Formaldehyde, using midget impingers containing sodium bisulphite, followed by spectrophotometric analysis;
- Radon gas in basement areas, using Track-Etch radon detectors;
- A range of volatile organic compounds, using a GC/MS in one or two locations per building, plus an outside control for each city;
- Bulk asbestos analysis of any materials in the air stream of the ventilation system, or exposed to the building occupants, which were suspected of containing asbestos fibers;
- Sampling and counting of airborne asbestos fibers;
- Sampling of selected water sources, and analysis for the presence of *Legionella pneumophila*, along with a hazard assessment of the water source for possible future contamination and dissemination of this organism.

RESULTS AND DISCUSSION

This survey yielded a large amount of data which can be broadly classified as either quantitative analytical data or more empirical assessments of the condition of the air handling systems. The quantitative data is shown in Tables I, II and III, with the qualitative data assessed and ranked on Figure 1.

Nitrogen dioxide, lower and higher range hydrocarbons, ozone, ammonia, and sulphur dioxide were not found above the detection limit of the method used and are, therefore, not included in these tables.

TABLE I. MECHANICALLY VENTILATED AREAS

Building Area	CO_2 (ppm) am	CO_2 (ppm) pm	CO (ppm) am	CO (ppm) pm	RSP (μgm^{-3}) am	RSP (μgm^{-3}) pm	Total HCHO (ppm)	VOCs (μgm^{-3})	Nicotine (μgm^{-3})	Radon (Bqm^{-3})	Airborne microbes ($cfum^{-3}$)
A (all)	628	545	4.3	4.1	41	35	0.03	1161	6.6	--	238
C (all)	408	408	2.5	2.7	53	53	0.01	64	<DL	40	340
F (all)	454	587	3.6	3.7	13	19	0.01	2030	4.0	18	111
I (all)	496	442	4.3	4.4	29	35	0.04	515	2.9	29	170
R (all)	528	492	2.5	0.8	20	28	<DL	--	--	33	374
Y (all)	473	491	3.5	3.3	14	12	0.02	276	3.5	81	600
Z (basement)	500	600	3.0	2.5	15	10	0.03	772	--	66	1000
MEAN	498	509	3.4	3.1	26	27	0.02	900	3.4	44	405

TABLE II. NATURALLY VENTILATED AREAS

Building Area	CO_2 (ppm) am	CO_2 (ppm) pm	CO (ppm) am	CO (ppm) pm	RSP (μgm^{-3}) am	RSP (μgm^{-3}) pm	HCHO (ppm)	Total VOCs (μgm^{-3})	Nicotine (μgm^{-3})	Radon (Bqm^{-3})	Airborne microbes ($cfum^{-3}$)
D (B-2F and 5F-8F	523	564	2.4	3.4	21	36	0.06	--	--	77	334
E (all but lab	600	622	2.7	6.7	92	56	0.06	824	<DL	62	768
G (all but reception	858	642	6.2	4.2	118	357	0.06	991	23.4	37	775
H (all but computer/conference rooms)	669	572	2.1	3.5	14	16	0.12	2693	3.9	44	116
J (all)	679	871	3.4	3.6	29	34	0.20	1206	41.9	29	533
K (all)	817	817	1.5	1.8	98	87	0.04	2859	18.3	48	268
L (all)	938	588	2.5	2.0	31	14	0.07	2033	2.8	59	157
M (total study area)	733	544	2.0	2.0	49	30	0.01	562	17.8	23	366
N (all)	746	750	2.0	2.0	16	16	0.02	414	15.1	275	254
O (complete study area except 3F conf, lounge, and 2F lounge)	692	713	3.3	2.4	33	--	0.02	935	--	29	273
P (all)	670	895	2.4	2.0	25	33	0.02	702	<DL	37	171
T (all)	731	613	2.5	2.0	32	24	0.03	146	9.0	209	156
U (Ground floor offices, basement)	600	475	3.0	2.5	100	85	0.04	--	--	37	500
V (all)	683	692	3.5	2.5	33	15	0.04	84	5.3	92	325
W (all)	556	600	2.7	2.6	46	52	0.02	910	<DL	532	372
X (all)	900	720	2.4	2.4	144	78	0.03	138	<DL	14,641	38
Z (all but basement)	575	658	2.3	2.3	45	78	0.02	--	3.0	--	454
MEAN	704	667	2.8	2.8	55	63	0.05	1036	10.0	106*	345

*This mean figure does not include the result from Building X.

TABLE III. MIXED VENTILATED AREAS

Building Area	CO_2 (ppm) am	CO_2 (ppm) pm	CO (ppm) am	CO (ppm) pm	RSP (μgm^{-3}) am	RSP (μgm^{-3}) pm	HCHO (ppm)	Total VOCs (μgm^{-3})	Nicotine (μgm^{-3})	Radon (Bqm^{-3})	Airborne microbes ($cfum^{-3}$)
B (all)	579	561	5.4	4.6	19	16	0.04	2420	25.7	37	377
D (3F-4F)	460	450	3.0	3.4	12	14	0.01	1366	<DL	--	271
E (CF lab)	1250	1850	3.0	3.0	80	130	--	599	--	--	259
G (CF reception	350	400	3.0	2.0	40	80	--	--	<DL	--	775
H (computer/ conference)	550	700	2.0	4.0	20	10	--	--	--	--	13
O (3F conf. lounge and 2F lounge)	508	617	3.3	2.7	25	--	--	--	2.7	--	516
Q (all)	620	573	2.4	2.7	55	13	0.03	329	2.1	33	533
S (all)	750	517	3.2	2.8	43	42	0.03	321	1.4	77	554
U (1F, 3F, CF cafe)	550	558	2.7	2.8	70	57	--	1070	1.1	--	481
MEAN	624	692	3.1	3.1	40	46	0.03	1018	4.7	48	420

CO	carbon monoxide	CO_2	carbon dioxide
RSP	respirable size particles	HCHO	formaldehyde
VOCs	volatile organic compounds	μgm^{-3}	microgram/cubic meter
ppm	parts per million	DL	detection limit
--	not tested for	Bqm^{-3}	becquerels/cubic meter
$cfum^{-3}$	colony forming units/cubic meter		

These 26 buildings varied widely, and as a result, there were many items found which were unique to a particular building. Specific problems included HVAC outside air intakes directly adjacent to parking lots. This type of problem is reflected in the "building configuration" section of Figure 1. Another problem unique to a building was an excessively high radon concentration in an area of Building X which required immediate attention. There were, however, some other more pervasive factors which were common to at least a sub-set of the buildings.

Since this survey was made in winter, most operable windows remained closed. As a result, many of the buildings that were not equipped with forced ventilation systems became somewhat stuffy, and this was reflected in elevated carbon dioxide concentrations, either throughout the building, or in certain pockets. Table III shows carbon dioxide levels overall in the naturally ventilated buildings to be slightly lower in the afternoon -- this coincides with observations that windows were more often open in the warmer afternoon hours than in the colder mornings. Table III also shows that most indoor pollutants measured were marginally higher in the naturally ventilated areas. An exception is carbon monoxide, which was generally lower and this may be due to the presence of underground parking garages under many of the sealed, mechanically ventilated buildings.

Low ventilation rates can be seen to affect more than half of these 26 buildings (Figure 1) and may be indicative of a general trend. Since the majority of underventilated buildings were older structures with little or no mechanical ventilation system, it demonstrates that indoor air quality problems are not limited to U.S. style "high tech" sealed buildings, but are just as likely in older buildings (at least in seasons of adverse weather).

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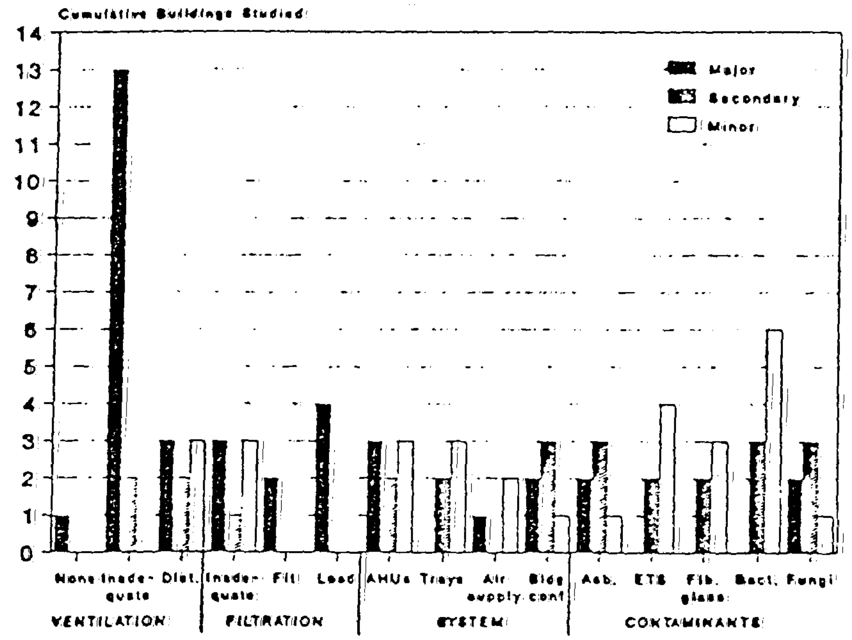
Figure 1. Indoor Air Quality Problems from 26 Swiss Buildings



None - no fresh air
Inadequate - limited fresh air
Dist. - poor fresh air distribution
AHUs - dirty air handling units
Trays - blocked or dirty condensate trays
Air supply - dirty air supply ducts
Bldg Conf - building design or configuration problems

Inadequate - low efficiency filters
Fit - poor fitting filter
Load - excessively dirty filters
Asb. - presence of asbestos
ETS - environmental tobacco smoke
Fib. glass - loose in air supply system
Bacteria - presence of infectious or allergenic bacteria
Fungi - presence of infectious or allergeni fungi

Overall, dust levels were higher in the naturally ventilated buildings not equipped with a filtration system. This is not surprising since dusts generated by occupant activities are more likely to be suspended in the room air for long periods instead of being drawn into a return system. In the more sophisticated buildings, a number of filter systems were found to be subjected to poor maintenance -- most commonly the selection of filters which are likely to rate less than 10% efficient in the respirable size range. Most commercial systems should be fitted with filters at least 20% efficient in this size range. A minority of these filters were poorly fitted, allowing air bypass, and four buildings were found to have filters which were excessively loaded. We still require a standard test which evaluates the ability of the filter to remove sub-micron size particles since these are the ones that penetrate deep into the respiratory system. We currently do not have such a test which is applied routinely to commercially available filters.

Due to poor maintenance, heavy dirt created problems in most of the air handling units inspected. Condensate trays and air supply ducts were also found to be

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loaded with various levels of dirt, slime or scale. Sampling for *Legionella pneumophila* in building water using the Legionella Rapid Assay method, revealed trace levels of the organism in five buildings, and strongly positive results in three buildings. These made up the majority of the bacterial problems found in this survey and demonstrate that this organism may be quite widespread in cooling and humidifying systems in Swiss buildings. In all twenty-six buildings, airborne microbial samples yielded wide ranges of fungal species. These were generally similar to outdoor air sample results. Better attention to hygiene of air handling systems may be one of the more effective ways of reducing occupant exposure to irritants in many Swiss buildings.

A minority of buildings exhibited poor use of fibrous glass, creating the potential for release of fibers either into the air stream of the ventilation systems, or directly into the room air. This is a maintenance item which is relatively simple to correct. More complex problems are raised by asbestos containing materials which were found to be a significant problem in two of the buildings examined, and secondary or minor problems in a further four. The control of fiber release from asbestos containing products in Swiss buildings may be a topic which requires significant educational effort in the future.

Environmental tobacco smoke was found to be a secondary or a minor irritant in a total of six of these buildings, usually associated with pockets of poor ventilation. Ventilation rates which maintained carbon dioxide levels consistently below 800 ppm, resulted in low levels of ETS, both as measured by nicotine and RSP levels.

The most room for improvement in these buildings was found with ventilation rates, which were inconsistent, and, in mechanically ventilated buildings, with overall levels of maintenance, especially with regard to filters and cleaning schedules. In particular, there is a need for a standard filter testing method for respirable dust removal. Furthermore, if these buildings are representative of many Swiss buildings, control of *Legionella* bacterium in cooling systems, improvement of hygiene of air handling units to maintain low levels of bacteria and fungi, and abatement of asbestos containing materials in exposed areas may need to be given high priorities in order to prevent immediate and long term hazards to building occupants.

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